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The Electronic Sandtable: An Application of VE-Technology as Tactical Situation Display.

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SUMMARY

In future battlespace scenarios huge amounts of highly dynamic information will be available due to the technical development of sensor, communication and information systems. This flood of available information may lead to mental overload of the military commander and cause a wrong mental model of the battlespace situation. Therefore advanced techniques for supporting the military commander and displaying complex tactical situation data in a clearly understandable way have to be developed and evaluated.

At the Research Institute for Communication, Information Processing and Ergonomics (FKIE) of FGAN a concept for preprocessing and visualizing incoming tactical data and three-dimensional geographical data has been developed. The concept includes the use of Virtual Environment-technology as a display system. This "Electronic Sandtable (ELSA)" testbed, as described in this paper, is based on a semi-immersive display technology. It facilitates a plastic stereoscopic visualization of three-dimensional data. It has been developed to be used to simulate a sandtable as commonly used by the Armed Forces for tactical education and training.

This paper presents the baseline concept of using VE-technology as an advanced tactical situation display. It is pointed out that, although the technology is commercially available, research in the area of ergonomics and human factors is essential for the advantageous use of such a system. The main ergonomic topics described in this paper include the stereoscopic visualization of the geographic and tactical data, the degree of abstraction and human operator interaction with the virtual scene on the "Electronic Sandtable".

1 Introduction

Within the scope of future scenarios there will be a high demand on detailed and highly actual information in military command and control (C^2). The demand will be met by complex information databanks, new sensor technology and fast electronic communication structures. Broad data acquisition, transfer and presentation will enable the military commander to get a variety of diverse information about the battlefield situation. The accomplished information dominance is more and more considered to be essential for a battlespace dominance.

However, the massive quantity of information is also hazardous. Especially in time-critical situations when tactical decision making under stress is required, relevant information may be overseen and a wrong mental model of the tactical situation is gained. That overload is likely to be reduced by using new technologies for data preprocessing and data presentation. Because data presentation is of critical importance in the whole process of decision making, ergonomic research is required to analyze the whole process of data presentation, considering new displays and interaction devices.

Especially using Virtual Environment (VE)-technology is promising. It was found to have high potential in presenting and interacting with complex amounts of data. Therefore VE will increase the clearness and intelligibility of a complex tactical situation. The situation scenario is not perceived as a complex of abstract information but as a pseudo-realistic model landscape. This is intensified by an intuitive, easy to learn interaction with the included objects.

2 Definition of Virtual Environment (VE)

The basic idea of generating and using a computer-generated artificial reality was mentioned first in science fiction literature at the middle of the 20th century. Due to rapid development of computer technology in the second half of the last century, a partly realization of this idea became possible. Nowadays these VE-Systems are commercially available and starting to be used for a broad range of applications (Alexander et al, 1999).

According to Bullinger et al (1997), Virtual Environments (VE) describe the computer-based generation of an intuitively perceivable and experiencable scene of a natural or an abstract environment. It is characterized by capacities for multi-modal, three-dimensional modeling and simulation of objects and situations. A further characteristic is the close interaction of the human operator with the system .

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In this connection, Virtual Reality (VR), has been defined by NATO HFM-021 (n.n.) as

"... *the experience of being in a synthetic environment and the perceiving and interacting through sensors and effectors, actively and passively, with it and the objects in it, as if they were real. Virtual Reality technology allows the user to perceive and experience sensory contact and interact dynamically with such contact in any or all modalities.*"

This definition of VR which is often used as a synonym to VE overlaps with VE. But whereas VE is application oriented, VR describes, strictly speaking, a total model of the reality, including all manifold facets of it. As this is not possible today and may not be possible in future, the further article will be use the term VE.

VE can be divided into at least three groups (Bullinger et al, 1997):

- *full-immersive VE* is characterized by a complete replacement of the reality by the virtual reality. The operator is completely included in the virtual world and does not perceive any (visual, acoustic) stimuli from the real word. A head-mounted display (HMD) is a typical full-immersive display.
- *semi-immersive VE:* The virtual scene is presented as a three-dimensional part of the reality. The operator perceives stimuli from the real world and additional stimuli from the virtual world. He cannot distinguish between real and virtual objects. Typical semi-immersive VE-Systems are workbenches which will be described later, and flight simulators.
- *Desktop VE:* The three-dimensional scene is presented on a two-dimensional display medium. Just interaction and navigation happen more intuitively. VRML-Browsers and Videogames work like this.

VE-systems are on their way of becoming used for different applications. Further information about military applications is given in Alexander et al (1999).

First, VE is a *research topic* itself. This involves basic research studies in computer science as well as interface design and ergonomics.

Secondly VE is used as a *research and development tool.* In this area VE Systems enable a very intensive and direct interaction with complex and abstract data. They enable new kinds of rapid prototyping. In an early stage of the design process CAD-models of products can be visualized and examined as if they were real. Improvements can be performed easily in real-time and the effects can be visualized immediately. This bring along advantages for the amount of time, the quality and the cost of the development cycle. In Fig. 1 an example for a virtual walk-through in the design process of a marine vessel's combat information center (CIC) is shown.

Another application is *teleoperation and telepresence.* This is not limited to remote control of unmanned systems. Moreover the operator gets the subjective feeling of really being there. This may enable higher situational awareness which is considered to be advantageous for this application. Furthermore, teleoperation is supposed to be useful for control of robots in contaminated areas, space or deep sea and special military purposes (reconnaissance, surveillance).

Finally, the area of *education and training* is a field of application. In contrast to conventional virtual simulation and simulators VE-systems are more flexible and adaptive. This is because one single VE-system can be used to simulate different types of vehicles or aircrafts. Moreover, training of individual soldiers' skills as well as team training become possible.

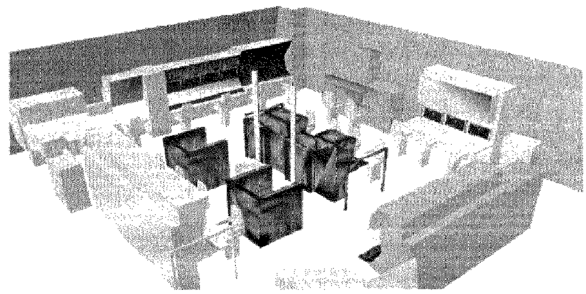

Fig. 1: Virtual combat information center (CIC)

The benefits of VE which have been shown in current approaches in these areas, make it a promising tool for further applications. One of these applications is a tactical situation display (TSD) of a Command & Control system.

3 Tactical Situation Displays (TSD) today

The basic function of TSDs is to display the current situation of own and reconnoitered enemy troops and facilities in the operation area to the commander of a military unit. Moreover the TSD is used for tactical planning of intended future operations. Quantity and quality of situation data are essential for an adequate operation planning (Grandt et al, 1997).

Today there are basically two different types of TSD's used by the strike forces.

The first one, shown in Fig. 2, is a *command post in the field*. The TSD used here works by means of paper & pencil. Actual information is transmitted by radio or field telephone and drawn into a map. It is obvious that in time-critical processes with large amounts of rapid changing information this leads to an overload of the operators. Furthermore, the display may not show actual or valid information and causes errors in decision making. However, it brings along the advantage that the commander is in the field: He gains high situational awareness, experiences the terrain, cover, weather, etc. and knows "what is really going on" at that place.

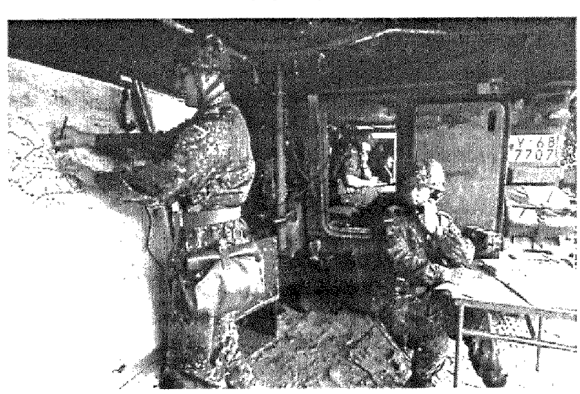

Fig. 2: TSD at command posts "in the field"

On the other hand there are *TSDs at operation centers*, as can be seen in Fig. 3. Tactical situation data is preprocessed and computers are used to visualize the results.

The advantages of these advanced TSD's are:

- actuality of data, provided that the communication infrastructure is fast enough,
- different views of levels of data aggregation and
- possibilities to include additional battlespace information.

But this flood of information may lead to an information overload; moreover data representation is still limited to two dimensions and techniques of interaction with data have to be learnt.

Fig. 3: TSD at operation centers

The approach of using VE as TSD first expands the two-dimensional visualization to three dimensions. This means that height information can easily be perceived. Additional elevation aids, like elevation profiles or color texturing, can be skipped and replaced by others (e.g. reconnaissance photos, weather data, etc.

The more important thing is that general interaction with data is simplified and happens more intuitively. This facilitates an experience of the tactical situation and the generation of a correct mental model. In an ideal VE-system the computer is not realized as an active entity, but becomes an invisible assistant which knows about user intentions and supports him (Alexander et al., 1997). Therefore operator workload is supposed to be reduced and situational awareness to be increased.

4 Approaches of VE-Technology in C²

The amount of studies and applications in the area of VE and VE-technology has increased rapidly recently. But whereas VE is close to become applicable in research and development and for single training applications, studies considering the specific use of VE in C² have just begun. Therefore knowledge in this area is limited and a lot of projects are in a conceptual phase.

Most research studies and projects in this area have been started in the past two years. Because of ongoing development in this area this is only a brief overview. Detailed information is given in Alexander et al. (1999).

Generally speaking, the approaches can be divided into two groups. The first group consists of concepts and long-term programs including VE-components. This is a top-down approach which takes place at high political level and typically application-oriented. The second group is characterized by specific VE-projects and laboratories. Consequently it follows a bottom-up approach and is presentation- and technology-oriented. Fortunately, there are links between both so that they meet and synergetic effects exist.

The Swedish *ROLF (Mobile Joint Command and Control System 2010)* is a long-term program. Its goal is to determine new possibilities for military commanders of using VE-Technology in mobile command posts. ROLF describes requirements for situational awareness, decision making and support, work methodology and organization of military crew and staff. The main idea is to use modern methods and technology to help a group of operators in difficult situations with complex, time-critical decision making. ROLF includes the *Aquarium* as TSD which is a semi-immersive VE-system. The TSD is used to visualize positions of own and enemy troops, positions of important institutions, terrain and weather data in different views. Data preprocessing is used to select the data displayed and ensures that only important information is visible (Sundin, 1996).

Especially the realization that in future battle scenarios all actions of the military commander will be in an unclear, vague environment and the importance of an information dominance led to the development of the *Command Post of the Future Program (CPoF)* of DARPA (1998). The program's goal is to accelerate the decision making process with ongoing reduction of the staff. Therefore new technology is needed to make maximum use of the whole human perceptory system in order to transmit maximum amount of information. This includes an interactive, three-dimensional visualization, three-dimensional interaction with computer-generated objects, presentation of inaccuracy and probability, integration of dynamic factors, three-dimensional symbolic, integration of natural language processing and integration of knowledge-based systems.

The second, more technology-oriented group of approaches is larger. Institutions and laboratories working in this area use different VE-technology. The technology is often reconfigured to be used for different research projects and experiments.

The *US Battle Command Battle Lab (BCBL)* performs conceptional studies as well as experimental analyses in a VR-laboratory. One goal is to develop a technology for a multi-media, scene-based application in education and training for organization and staff functions. This system shall be connected to the internet to increase the range of application (Heredia, 1999).

At the *US Naval Research Laboratory (NRL)* an advanced battle planing and management system has been developed. The system works with a semi-immersive display and enables multi-modal interaction. It was found to be very suitable for virtual-prototyping, interactive mission planing and increasing situational awareness (NRL, 1997).

Similar approaches, like *Mirage* of the Army Research Lab (ARL) (IST, 1997), the *Visualization Architechture Technology (VAT)* of the Crewstation Technology Laboratory (CTS) (Achille, 1998) or the *Electronic Sand Table* of MITRE Corp. (MITRE, 1998) also use a semi-immersive VE-technology, as described further on.

Other approaches use full-immersive VE or desktop-VE respectively (Dockery & Hill, 1996; Morgenthaler et al, 1998).

5 The Electronic Sandtable (ELSA)

The Electronic Sandtable has been developed as an advanced display for tactical information in mission planing, control and rehearsal. The concept is based on the sandtable metaphor. The military sandtable, as shown in Fig. 4, consists of a sandy model landscape with simplified objects representing woods, buildings, points of interest or military units. It is broadly used in military education and training.

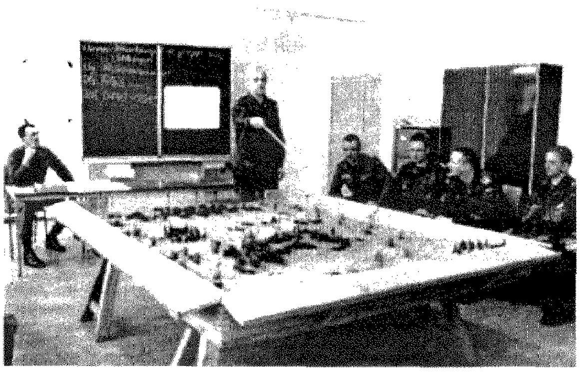

Fig. 4: Sandtable in military education

But the traditional sandtable is static; all changes of deployment have to be done manually. Each change of region is very time-consuming and has also to be done manually. Moreover the accuracy for representing real geographic data is poor.

It is intended to model the sandtable by means of a VE-system. This way dynamics, real-time interaction and changes of the point-of-view can be included while the benefits of the real sandtable remain.

For this purpose geographic data and tactic data have to be visualized stereoscopically. It is intended to create a model landscape, in which dynamic battle scenario is included. Furthermore additional functionality is added, e.g. visibility, range of weapon systems, etc.

5.1 Structure and Technical Implementation

The Electronic Sandtable has been implemented as a testbed at the Research Institute for Communication, Information Processing and Ergonomics (FKIE). A draft of the technical setup is shown in Fig. 4.

Because of the large size of geographic databanks and the need for real-time interaction, the underlying structure has been arranged in two stages (Alexander et al, 1997).

The first stage is executed offline. In this stage the scene graph is determined. The scene graph is a hierarchically ordered databank of all polygons included in the visible scene.

Originally all data is separated in different databanks, which means:

- digital terrain elevation data (DTED),
- digital feature analyses data (DFAD),
- textures (e.g. reconnaissance pictures),
- single geometric objects (buildings, tanks, airplanes) and their attributes.

In a semi-automatic process data and objects are selected, integrated and re-ordered with respect to maximum rendering performance. This databank is called the scene graph. Afterwards the structure of the scene graph stays constant without any changes.

In the second stage additional data is constantly added and the scene graph is visualized online. The additional data, i.e. tactical situation data and data from external

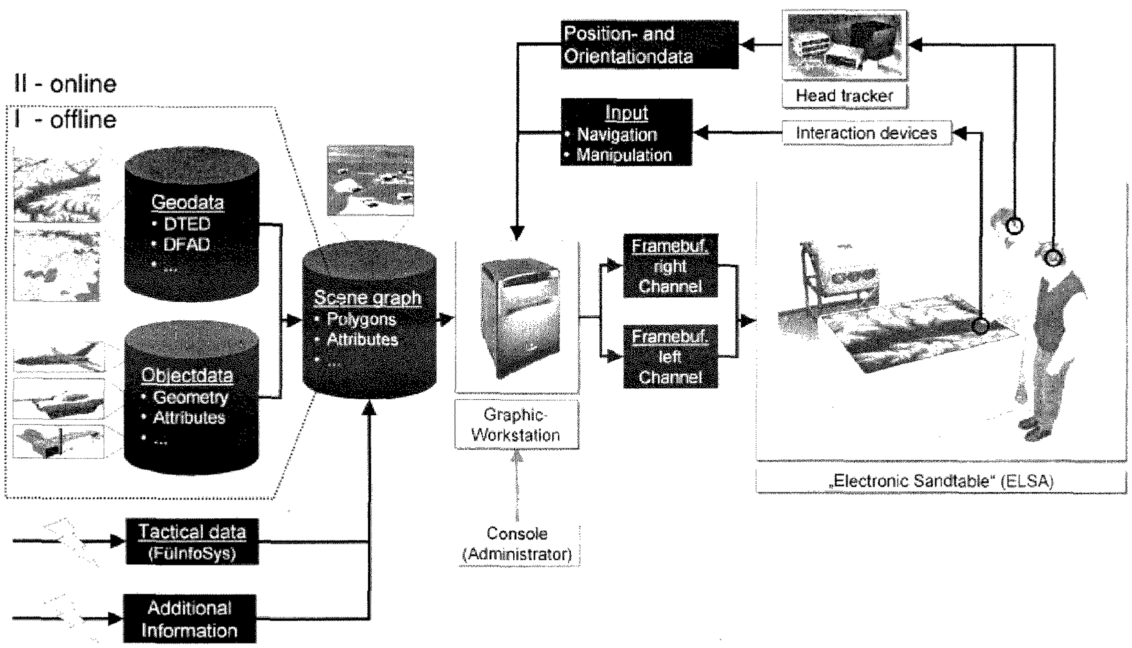

Fig. 4: Structure of the Electronic Sandtable (ELSA)

data sources, is linked to objects of the scene graph. Additional input of external data using different protocols (DIS, HLA) shall also become possible in future. The incoming data controls position and status of military units. Additional data, like actual situation videos or information of knowledge databanks, can also be included.

After that the rendering subsystem selects the visible subset of the scene graph. Out of this two separate projections are calculated and written into the two frame buffers. Then both frame buffers are visualized alternately on a horizontal plane.

The human operator interacts with the scene by means of different interaction devices. The inputs serve as commands which affect the objects of the scene graph. The actions are logged for later analysis.

The operator is able to select different visible areas for navigation. The borders of the area serve as one input variable of the rendering subsystem. Additionally each of the operator's movements is tracked by a head-tracker. The position output of the tracker is another input variable of the rendering subsystem for new projection calculation.

5.2 Generation of the Scene Graph

The scene graph is the output of the first stage described in chapter 5.1. The generation process itself is offline and semi-automatic. As far as possible COTS-products are used.

The process is divided into a data selection, preprocessing and optimizing phase.

Preprocessing and optimizing are necessary because terrain and feature data are generated from geographic databanks. These databanks were designed with regard to different requirements which makes them unsuitable for a real-time, realistic visualization.

5.2.1 Data Selection

In the first step an area of interest is selected and the relating terrain (DTED) and feature (DFAD) data is extracted. Additionally, links between features and geometric objects are defined. Afterwards the selected data is saved in a temporary buffer which has to be preprocessed and optimized for visualization.

The *geographic data* available is divided into (Helmuth, 1996):

- *Raster data:* pixel data (e.g. scanned paper maps),
- *Picture data:* geo-referenced or non-referenced aerial or satellite photos.
- *Vector data:* surfaces (e.g. woods, lakes), lines (e.g. streets, rivers) or points (e.g. power poles, points of interests, bridges, towers) with the position of their bases and attributes. For visualization vector data is linked to detail objects.
- *Matrix data:* data in matrix format of a specific resolution. Usually, terrain data is organized like this.

Geometric objects are components which are linked to geographic data, especially geographic vector data, and tactical situation data. They include a geometric description of the object (e.g. tanks, airplane) and additional information (e.g. unit status, damage reports, etc.). At the stage of real-time visualization they are shown at the position given either by the geographic data or the tactical situation data. General geometric objects are often automatically constructed. However, more sophisticated models have to be designed manually either by a CAD-program, a modeling software or out of an object databank.

For later selection operations *attributes* have to be added. Attributes can be divided into geometric and general attributes. While geometric attributes (length, width, height) are the same for each object, general attributes are dependent on the kind of application. Such attributes might be population data (sociology), pollutant emission (environment) or tactical information (military).

5.2.2 Data Preprocessing

Consistency and integrity are highly important criteria for databanks. If datasets of more than one databank are merged, contradicting data might emerge and cause errors. Those errors are based on errors or inaccuracies in the original databanks, different data resolution or different actuality of data acquisition.

As soon as consistency and integrity is proved, the process of merging terrain and feature data starts. Geometric objects are appended and, if necessary, adjusted to ground level.

Finally the triangulation process starts and determines polygons for visualization.

5.2.3 Data Optimizing

For real-time visualization the amount of rendered polygons has to be minimal. Therefore the databank system transfers only information about the visual subset. Non-visible parts outside the field of view are clipped.

For further reduction the databank is re-organized and the scene graph is tiled. In the visualization process the distance to the point of view sets the level of complexity for each tile.

Different levels of complexity, also called levels of detail (LOD), are another technique to reduce polygons. LOD means more than one representation of different levels of complexity (different amount of polygons) for the same subset. This means, if a subset gets closer to the point of view, a higher LOD with more polygons is visualized.

Using these techniques data is re-organized with regard to visualization issues. The output of this process is the scene graph which is visualized in real-time in the second stage.

5.3 Display Technology

The display technology used for three-dimensional visualization is a semi-immersive virtual workbench. This concept has originally been developed by Krüger & Fröhlich (1992). The baseline concept is shown in Fig. 5. Today it is used for various applications.

A projector projects two computer-generated, time-alternated pictures onto a mirror. The mirror reflects them to a horizontal focussing screen. By using shutter glasses, i.e. LCD-glasses shading each side alternately synchronous to the projection, the operators perceive two separate pictures for the right and the left eye. The synchronization works by an emitter sending infrared signals synchronously to the picture projected.

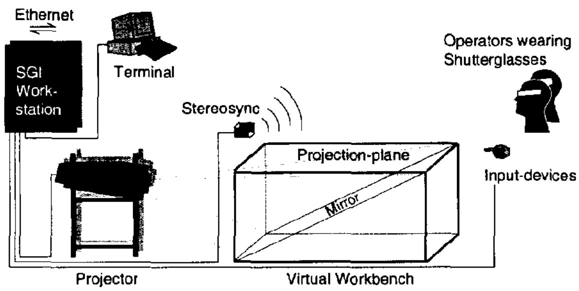

Fig. 5: Principle of a semi-immersive virtual workbench

Finally, both pictures perceived are fusioned by the cerebrum to a single, three-dimensional model.

6 User Interface

The design of the user interface of VE-systems has been found to be one of the main criteria of quality for its application. The Electronic Sandtable serves as the interface between the real environment on the one hand and the virtual scene on the other hand. Moreover it uses a different metaphor than the desktop-metaphor used in various computer applications. Therefore new interaction techniques and procedures have to be developed, analyzed and optimized according to a high performance of the human-computer-system (Alexander, 1999).

This includes visualization, interaction and cooperation in a virtual scene.

6.1 Visualization

A realistic, three-dimensional visualization of terrain data has to consider the physiological procedures of visual depth perceiving. These procedures have been studied extensively, and several different hypothesis for depth perceiving exist.

Each hypothesis postulates the existence of depth cues. The classic depth cues will be summarized later in this chapter. Especially the depth cues of stereoscopic disparity and parallax are of critical importance for the application of the Electronic Sandtable.

A computer-based visualization has to take into account different depth cues. For stereoscopic visualization different viewing models exist. The common models will be presented in this chapter as well.

6.1.1 Visual Perception

The physiological visual system consists of the eye as sense organ for stimulus acquisition, the optic nerve for stimulus transfer and the optic center of the cerebrum for stimulus processing.

According to Schmidt & Thews (1995) the human eye can be divided into two subsystems:

- Subsystem 1 is responsible for the refraction of incoming light. Its main components are: Iris (control of incoming light intensity), lens (refraction), vitreous body (stability) and diverse muscles (adjustment).
- Subsystem 2, jointly with the central nervous system, transfers the light to stimulus signals of nerve cells. It consists of the retina with its two different light receptors.

The stimuli are transferred via the optic nerve to the optic centers of the cerebrum. Here the optic sensing and recognition takes place.

Visual perception is generally based on three stages of perception (Kelle, 1994):

The first stage is an egocentric perception of the own person. This allows a separation of objects of the own body and other objects, making possible to determine the own position with regard to other objects and an *absolute depth perception.*

The next step is a comparision of the objects in the environment, allowing a *relative depth perception.*

Finally memory, experience and internal processing mechanism lead to *depth cues* being fundamental for spatial perception.

6.1.2 Depth Cues

Depth cues are visual system cues which enable perceiving of spatial dependencies (Hodges, 1992; Schmidt & Thews, 1995). The can be divided into monocular and binocular cues.

Monocular cues are valid for perception with one eye only.

The main monocular cues are:

- perspective,
- difference in size,
- known dimensions of objects,
- shading,
- light and shadow,
- accommodation.

The binocular depth cues require the total binocular eye system. They influence the perception of short to medium distances.

Traditional binocular depth cues are:

- convergence:,
- disparity and parallax.

Additionally to these static cues there are dynamic cues which have large influences on the depth perception for medium distances (17 –29 m) (Kelle, 1994).

6.1.3 Disparity and Parallax

Disparity and parallax have a large influence on depth perception and are the main depth cues for stereoscopic visualization. Therefore they are described more detailed.

The distance between both eyes leads to different representations of an object on the retina of the right and the left eye. Both eyes perceive the object with a different perspective. The difference between both pictures is described by the disparity.

If an object is focussed, it is represented at the fovea of both eyes. A round spatial surface exists (horopter), representing all objects on it on corresponding retina areals. Objects at positions different from the horopter are represented at non-corresponding retina areas. If the distance from the horopter is not too large, the cerebrum fusions the right and left picture to a three dimensional model. If it is too large, disturbing double pictures are perceived (Schmidt & Thews, 1995).

Disparity is a mathematical dimension and cannot be determined practically. Therefore the dimension of the *stereoscopic parallax* has been introduced. For this a reference level has been used which is parallel to the eyes' level and runs through the fixation point.

Parallax has been defined as (Helmholtz, 1910, ref. in: Kelle, 1994):

$$p = b_a \times a \times \frac{t}{e * t + e^2}$$

p = parallax
b_a = inter ocular distance
a = distance eyes / reference level
e = distance reference level / object
t = distance eyes / object (=a+e)

Parallax is also a dimension for depth separation and depth perception. Therefore it is deduced that depth perception decreases with square distance. Furthermore it increases linearly with inter ocular distance.

According to Kelle (1994), stereoscopic disparity and parallax has been found to be useful only for near and medium distance (maximum of 6-9 m).

Visualization of geographic data of large scale means a large distance between eye point and surface. It can be concluded that exact modeling means that parallax and stereoscopic depth perception will be very low. Instead inter ocular distance has to be modified to several meters evoking a higher stereoscopic depth perception.

6.1.4 Stereoscopic Projection Models

For three-dimensional stereoscopic visualization three different projection models are commonly used. Their baseline geometry is illustrated in Fig. 6.

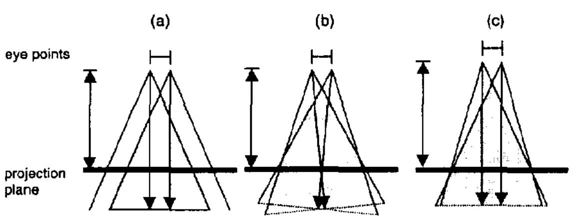

Fig. 6: 3 projection models: (a) parallel projection, (b) rotated projection, (c) window projection

In Computer Aided Design (CAD), aerial photo analysis and for head-mounted-displays (HMD) *projection models with parallel line of sights* are used, as shown in Fig. 6 (a). They are based on the assumption of a center eye-point perpendicular to the projection plane. Right and left projection are calculated by using offset values and parallel shifting the projection right and left. The disadvantage of this model is that the scene can only be visualized underneath the projection plane. This is inconvenient for the concept of the Electronic Sandtable, because the scene would always be located beyond hand range. Another disadvantage is clipping at the borders of the display as there are missing visual information for either the right or the left eye. Especially at large displays this is very irritating for operators.

Fig. 6 (b) shows the geometry of a *projection model using rotated line-of-sights*. Here the projections are rotated in the way that both lines-of-sight meet in the projection plane. The lines-of-sight are not perpendicular to the projection plane. The concept remains the same, no matter if the scene, the eye points or both are rotated. It enables a visualization underneath and as well as above the projection plane. There are no irritating effects on the borders of the display either. But because of the special geometry, an error of vertical parallax appears. This can be observed especially at the borders of the display, where both lines meet at a point above the projection plane. This leads to a "winding"-effect and the scene seems to be projected on a cylinder rather than a plane. The error is perceived especially on large displays.

The last projection model uses *window projection*, which means that two windows are introduced through which the virtual scene is perceived. The windows are positioned in the same level as the projection plane. Both lines-of-sight meet at the projection plane and remain perpendicular to it. This is correct for the middle and the border of the projection area. In this model, stereoscopic parallax is only dependent on the distance to the display and no vertical parallax is introduced.

This model is used for the Electronic Sandtable. As shown in Fig. 7, the model for each eye is described by an asymmetric pyramid. This means, the perpendicular line through the top does not meet the center of the pyramid basis.

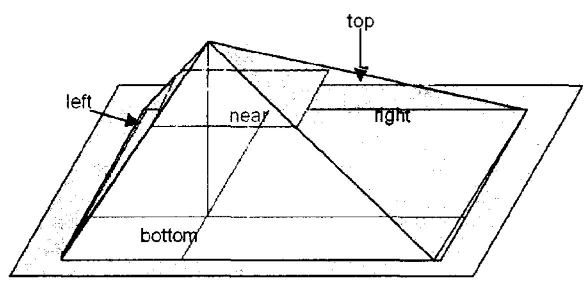

Fig. 7: Right and left asymmetric projection pyramid and boundary surfaces (clipping planes)

For each projection six parameters are used to identify the pyramid. They include the values for front, back, top, bottom, left and right clipping plane. These values are calculated by x,y,z-position of both eye-points, scale factor and the display size as input.

Pilot experiments have shown good results for this projection model. Only little perspective error due to tracking of the real eye position was determined. In future, this error will be minimized by calibrating the tracking equipment.

6.1.5 Future Research in Visualization

So far only real-size shapes have been visualized. In future geographic data of different scales will be used. To evoke a stereoscopic depth perception, an adaption of the scale factor for elevation as well as the dimension of inter ocular distance is necessary.

However, the adaption may lead to either too flat or too heigth depth perception. Both is not wanted and therefore research studies will be done concerning the correct determination of both parameter.

Another research topic is the maximum vertical range of the display. The display technique causes contradicting depth information, because both eyes accomodate on the projection plane, but fixate an object closer or more far away. However, if the virtual scene is too close, parallax becomes too large and the cerebrum cannot fusion both pictures. Therefore another research topic will be to determine the maximum useful vertical display range and the variability of human sense perceiving.

Pilot experiments in this area have been started and are currently going on.

6.2 Interaction

Interaction with the databank means navigation in the scene and manipulation of virtual objects. For both subgroups procedures (software) and interaction devices (hardware) have to be designed, evaluated and analyzed according to the application.

6.2.1 Navigation

Navigation can be divided into: Navigation within the databank system and navigation within space.

The first, *navigation within the databank system*, encloses different procedures for search and selection of datasets. This is a general topic and is not of special interest for VE systems. Therefore it will not be described in this paper.

Navigation within space means a change of position or orientation of the observer. This is, generally speaking, a modification of display area. A first implementation sets a starting position and orientation for the observer. Both can be modified by user input. There are many possibilities for designing the navigation procedure of the graphic user interface (GUI).

One is an adaption of the procedures used by MS Windows© or OS Motif©. An example of this can be seen in Fig. 8. In this concept, the operator has to turn dials or move sliderbars at the sides of a software-window to modify the display area. For desktop computers this concept is familiar, often used and nearly standard. However, on large displays it was found to be very inconvenient. The reason for this is that reaching for the navigation control means to move a cursor a long way across the display and this takes a lot of time.

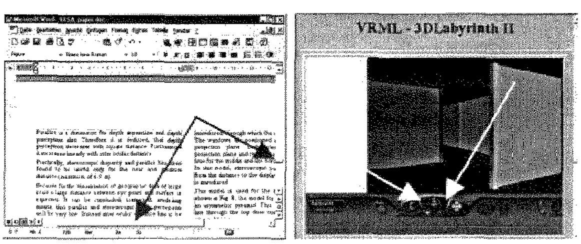

Fig. 8: Different desktop navigation concepts.
left side: MS Windows © and sliderbars;
right side: Cosmoplayer© and virtual cockpit

Secondly, concepts for "virtual cockpits" are possible, as shown in Fig. 8. The operator moves/flies through the scene by controlling a throttle and a virtual control stick shown in the lower middle of the GUI. This technique is often used for desktop-VE systems, especially for VRML-applications. However, for larger displays and semi-immersive VE-systems it has been found to be not efficient enough.

For reasonable use of the benefits of VE, the interaction has to be more intuitively. The concept of *"grab-and-move"* describes a first step in this direction. In this concept the operator grabs the scene and slides it to any direction. First trials using an implementation of this concept show that navigation becomes rather easy and fast.

In the actual experimental setup a trackball is used as main interaction device. Missing degrees of freedom are simulated by additional switches on the device. For future studies evaluations of other devices are planned. One of those will be a virtual laser pointer which makes pointing, selection and navigation possible.

6.2.2 Manipulation

Manipulating the objects of the virtual environment will use the same devices as for navigation. A switch or control bar is used to toggle between navigation and manipulation mode. In manipulation mode the operator has to be able to select objects and choose special control operations.

Main control operations are:

- generation of new objects,
- editing attribute values,
- erasing,
- placement,
- orientation,
- movement,
- editing terrain data.

Generation, editing and erasing of objects can easily be implemented. But placement, orientation, movement and editing of terrain data are more difficult, because interactions between different objects of the scene graph have to be considered. This can easily lead to errors in the structure of the scene graph.

For correct *placement and orientation* of objects in the three-dimensional space elevation information about the base point is necessary. Moreover, if the object is placed on oblique terrain, it has to be oriented correctly. This information can only be derived from the original geographic databank which is not a part of the scene graph. For this reason data exchange with the original geographic databank has to be possible.

Movement of objects is even more critical. It describes the process of detaching the object out of the scene graph and re-placing it at another position. A trivial implementation would be to erase the old object and generate an identical new object at the new place. But intelligent movement algorithms should enable a movement of the object while simultaneously fixating it on the ground level (*terrain following*).

More complex edit operations of the terrain databank are very difficult, because the original geographic databank has to be modified, stored and re-converted into a new scene graph. As said before, this has to happen offline.

Consequently the actual setup of the Electronic Sandtable does not support these operations.

6.3 Cooperation

The concept of the Electronic Sandtable has been designed to enable multiple operator working in the virtual scene. It has to include cooperation concepts.

In contrast to full-immersive VE, in semi-immersive VE all operators are present at the same location. Communication and inter-operator interaction happens the natural way. Therefore mainly human-computer interaction issues have to be analyzed. These main issues and problems will be discussed in the following.

A correct perspective visualization of the computer-generated picture is limited to only one single operator due to technical reasons. The technically possible frame rate is limited to a maximum of 144 Hz. For stereoscopic visualization the rate is cut into halves (72 Hz). An additional operator would mean to cut it into halves again (36 Hz), making flickering as well as occurring of hazardous separation of single pictures likely to appear. In a word it can be summarized that with today's technology only calculation and stereoscopic presentation for a single operator is possible. Further operators will perceive a perspective error.

One way of dealing with the problem would be to track more than one operator and to calculate an average position. Average position does not necessary mean the arithmetic mean, it could be a more complex formula determined by subjective ratings. This way the perspective error might be minimized and might not be subjectively perceivable.

Apart from visualization, cooperation also has effects on interaction and manipulation. For different operators working in a virtual scene, two main concepts exist. The concepts are drafted in Fig. 9.

The *conference concept* is characterized by an active presenter and passive participants. The presenter is able to navigate and manipulate, whereas the participants are following the presentation. There is no real cooperation taking place.

On the other hand, in the *workshop concept*, all participants become active. However, they are given different rights for access. At the beginning of each session, an operational area is set as working region. Afterwards participants are able to work in this region. This concept is not limited to human-computer interaction but has to include cooperation procedures between session participants as well.

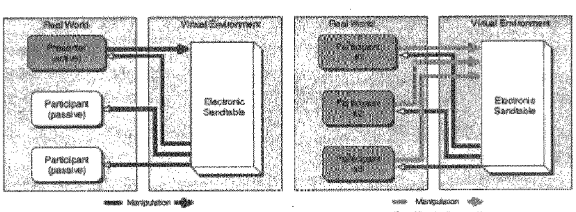

Fig. 9: Conference (left) and workshop (right) concept

A typical example is handing over an object. Participant #1 selects an object and gets access rights for it. For exact placement he hands it over to participant #2. Access rights move over to participant #2 as well. Finally participant #2 drops the object and loses access.

These concepts require the introduction of new procedures and an intense research in this area. Because reality is still to be modeled natural procedures serve as input for the model. But just modeling reality does not consider that VE-systems have much more capabilities. Therefore new advanced concepts have to be formulated, to optimize use and gain benefits of the system.

7 Conclusion and Future Research

In this paper the baseline concept of using semi-immersive VE-technology as advanced TSD has been described. The approach has been shown to be promising and advantageous.

It has been emphasized that human factors and ergonomics are the main issues for reasonable VE-application. Main research issues were found to be visualization, interaction and cooperation. But these topics cannot be analyzed separately, because interactions between them exist. In this paper some research issues were introduced and results of ongoing research studies in the area of visualization were presented.

But even if in future the system works as it is supposed to be, one question to be answered still remains: The question for quantification of the profit and gain of using VE-systems. The key criteria for answering this question will be performance of the human-VE system.

For this reason human performance metrics will have to be introduced, formulated and analyzed. They should be as fundamental as possible, but still take into account the characteristics of the application.

Jointly with other basic research studies they will be the key issues of future research in this area.

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